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A COMPUTER MODEL OF SACCADIC SUPPRESSION.(U)
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Final Report

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"A Computer Model of Saccadic Suppression"

William J. Ohley, Principal Investigator

January, 1981

Abstract

This work is organized into two sections. Section 1 reviews the direct experimental results of the project, and is in review as a paper for the Journal of Perception and Psychophysics: "A Sensory Model of Saccadic Suppression. Section 2 is a proposed extension of the work and has been submitted as a formal proposal to AFOSR. "Cluttered Displays: An Experimental and Computer Modeling Approach."

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Eye movement, saccadic suppression, vision during eye movement, spatio-temporal interactions within human visual system.

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This work provides a quantitative model of saccadic suppression in which the suppression of vision is shown to result from direct interaction of the spatial and temporal properties of the human visual system. The model can be divided nto a spatio-temporal impluse response function, and a psychophysical detection process. The space-time impluse response function is derived from the retinal line spread function and know temporal response characteristics of humans. By assuming linearity, the saccade like motion of a slit of light passing over the relina is convolved in two dimensions with the space-time function. (cont'd)

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Inclusion of a single threshold decision rule then allows excellent prediction of experimental results.

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A SENSORY MODEL OF SACCADIC SUPPRESSION

William J. Ohley
and
Craig MacInnes
Dept. of Electrical Engineering
University of Rhode Island
Kingston, R.I. 02881

Abstract

There have been many mechanisms postulated to explain the phenomenon of saccadic suppression. To a large extent, previous work has relied on a qualitative discussion of experimental evidence. In the work reported here, we provide a mathematical model of saccadic suppression. The model makes use of the line spread function and temporal response characteristics in humans to generate a composite space-time impulse response. By assuming linearity, the motion of a slit of light passing over the retina is convolved in two dimensions with the space-time function. Inclusion of a single threshold decision rule then allows prediction of results from previous investigations. Thus, in the instances described here, saccadic suppression is shown to result from direct interaction of the spatial and temporal properties of the visual system.

Introduction

Suppression of vision during the course of voluntary saccades has been widely reported (Matin, 1972, 1974, 1976, Volkman, 1978, Bridgeman, 1977, Sakitt, 1976, Stark, 1976, Shebilske, 1976, Brooks, 1975, Mitrani, 1975, Mohler, 1975, Mackay, 1970). While it is agreed that saccadic suppression can occur for luminance, contrast, and perceived motions, the exact mechanisms of suppression has not been well established.

In general, the causes of reduced vision have been attributed to either retinal simulation, an extra retinal signal, or a combination of both factors. Brooks et al., (1975) have demonstrated, for stroboscopic test flashes on various backgrounds, that similar time courses of suppression could be produced by "normal" saccadic eye movements and by "saccading" the visual image across the retina during eye fixation. Mitrani et al. (1975) also suggested that a significant amount of visual deterioration results from movement of contours over the retinal field. Contrastingly, Bridgeman (1978) has argued in favor of an extra retinal signal arising during saccades to cause threshold evelations. Matin (1976) and Volkman et al. (1978) suggested that retinal stimulation combines with neural effects to produce suppression.

In most work on saccadic suppression, description of possible mechanisms have lacked any quantitative modeling. Thus, the purpose of this work was to develop a mathematical model of saccadic suppression. Because information available to the retina during saccades is a dynamic event in space and in time, the spatio-temporal properties of the visual system must be carefully considered in any modeling approach.

Visual spatial properties have been described by either a line spread function (LSF) (Wilson, 1978, 1979, 1980) or modulation transfer function (MTF) (Cornsweet, 1970). It has been shown that these functions are complimentary via the Fourier transform. Furthermore, they exhibit a reduction in sensitivity as distance is increased from the fovea.

Temporal response characteristics have been described in terms of a flicker fusion response or as a temporal modulation transfer function (Cornsweet, 1970).

More recently, attention has been directed towards investigation of combined spatial and temporal properties. It has been shown that measured visual spatial properties can be modified by the temporal characteristics of the stimulus (Hines, 1976, Arend, 1976). There is also evidence that both temporal "sustained" and "transient" channels exist, each with distinct spatial MTF's (Spitzberg et al., 1975; Grunau, 1978).

Wilson has recently investigated spatio temporal characteristics for transient channels (Wilson, 1980). Since saccadic eye movements are relatively rapid, it is possible to apply such results from transient channel work directly to visual sensitivity during saccades.

Model Development

The model developed in this work can be divided into several sections: A spatio-temporal impulse response function, and a psychophysical detection process.

Input to the model is a two-dimensional retinal stimulation function $f(x,t)$. This represents the magnitude of light falling on the retina as a function of a single spatial dimension x in units of angular degrees, and of time, t, in seconds. Output from the model is in terms of what

was visibly described by a subject in a particular experiment. The experiment used to validate the model is described in the validation section.

A fundamental concept applied here is the treatment of the space time properties as a combined two-dimensional function. The space time function $h(x,t)$ is derrived by assuming it is separable:

$$h(x,t) = h_1(x) \cdot h_2(t) \tag{1}$$

where $h_1(x)$ is the LSF and $h_2(t)$ is the Temporal Response Characteristic. From recent studies for foveal regions of the retina:

$$h_1(x) = \exp\left(\frac{-x^2}{\sigma_e^2}\right) - \frac{k\sigma_e}{\sigma_i} \exp\left(\frac{-x^2}{\sigma_i^2}\right) \tag{2}$$

The constants σ_e, σ_i and k were taken from previously reported studies (Wilson, 1978): σ_e 0.64, σ_i = .193 , K = .90 and x is eccentricity in degrees with the zero reference at the foveal center.

It has been shown for different positions on the retina that the form of $h_1(x)$ remains double gaussian, yet the constants σ_e, σ_i and K can change significantly. However, for the particular experiments simulated in this work, retinal stimulation was confined to 3 angular degrees. Thus only equation (2) was utilized to represent the spatial response.

There have been several different forms reported for $h_2(t)$. In this case, the simple form of

$$h_2(t) = \exp(-t/\tau) \tag{3}$$

was assumed where from temporal response data τ = 10 msec.

Thus the combined response function, graphed in Figure (1), and expressed analytically is:

$$h(x,t) = \{ \exp\left(\frac{-x^2}{\sigma_e^2}\right) - \frac{k\,\sigma_e}{\sigma_i} \exp\left(\frac{-x^2}{\sigma_i^2}\right) \cdot \exp(-t/\tau) \tag{4}$$

In order to predict the response g(x,t) to a given retinal stimulus, f(x,t), use is made of the convolution integral:

$$g(x,t) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} h(\xi,\tau) f(x-\xi, t-\tau)\, d\xi\, d\tau \qquad (5)$$

In the context of the model, g(x,t) is the information supplied to a psychophysical detector and f(x,t) is the space-time course of retinal stimulation during a saccadic eye movement. If it is assumed that the stimulus is a point of light that is swept across the retina at a constant velocity, in the space time plane f(x,t) would appear as a diagonal impulse train over the plane. For each instant in time, a new spatial coordinate is stimulated. If, on the other hand, the movement of the light in the x direction is stopped while it stays on, then at that point, the pulse would run parallel to the t axis.

In naturally occuring saccades, a diagonal relationship does not exist between the horizontal angle and time. Yarbus, 1967, gives it as a cosine relation:

$$x = \frac{x_0}{2}\left(1 - \cos\frac{\pi t}{T}\right) \qquad (6)$$

where t is time in seconds x is the rotation angle in degrees, T is total saccade duration time and x_0 is the final angle at the saccade end. For a point of light of intensity I_0 turned on at t=0 and off at $t=t_1$. Equation (6) yields:

$$f(x,t) = \begin{cases} I_0, & 0 < t < t_1 \text{ AND } x_0 < x < \frac{x_0}{2}\left(1-\cos\frac{\pi t}{T}\right) \\ 0, & \text{otherwise} \end{cases} \qquad (7)$$

using Equation (7) and (5) a response function $g(x,t)$ to saccadic stimulation of the retina can be found. Loosely, $g(x,t)$ can represent information ariving at the visual cortex. Rigorously, it is only an intermediate step in the model. In order to predict what is perceived, a psychophysical detector must be applied to $g(x,t)$. If the observer is asked to describe something about the spatial character of the stimulus, this can be defined in the model as a projection, $g_1(x)$, of $g(x,t)$ along x. The form of the model as presented here next assumes that a contrast decision rule is applied to the projection $g_1(x)$. That is, over the retinal field of interest, in this case 3 horizontal degrees, the perceived part of $g_1(x)$ will be some percentage, K, of the maximum value of $g_1(x)$.

P(x) the perceived part of $g_1(x)$ is:

$$P(x) = g_1(x) \quad \text{For } g_1(x) \geq K \cdot MAX(g_1(x)) \tag{8}$$

The threshold factor k is chosen by forming a least square fit to experimental data.

Validation

To demonstrate the ability of the model to predict experimental results, a previous investigation was chosen to be simulated (Matin, 1972). In this experiment, the subject was required to make voluntary left to right 4^{o} horizontal saccades between two fixation points. At the 1^{o} position a vertical slit of light located beneath the right fixation point was turned on. The slit was left on for varying times during the course of the saccade while the subject compared the apparent horizontal length of the slit, often seen as a blur in the visual field, to a comparison line displayed 500 msec after the saccade ended. The results are shown in Figure (2). The ordinate is perceived slit length and the

absissa is duration of slit illumination. Essentially, the blur was only perceived when the slit was turned off during the saccade. When the slit was left on past the end of eye movement (t 30 msec), the length of the blur decreased until only the slit itself was perceived; the blur was said to be suppressed.

To simulate the experiment using the model as developed previously it was only necessary to specify a series of retinal input functions $f(x,t)$ corresponding to each duration time of the slit target. Once the projection $g_1(x)$ was calculated, the k factor in the decision was found by a least squares fit over the range of calculated results.

Results

The results of the model are presented in three ways: Figure 3 and 4 show the intermediate $g(x,t)$ function for a short duration slit (15 msec), and a long duration slit (82.5 msec) respectively. Figure 5 is a sequence of the $g_1(x)$ projections as slit duration is increased from 12.5 to 62.5 msec. Figure 6 shows the results of applying a decision rule with a k of .33. The calculated blur length is plotted on the same axis as Matin's data.

Discussion

The model presented in this paper demonstrates the profound results that can be obtained by considering continuous interactions in the spatial and temporal domains. While it contains assumptions of linearity and homogeniety in the retinal receptors, for the narrow visual angle considered these assumptions appear reasonable. Perhaps the most interesting phenomenon presented by the model is illustrated by Figure 5 and in the latter portions of the sequence in Figure 6. Here at the point in

the (x,t) plane or x projection where the eye begins to slow down (t: 27 msec) there is a strong interaction between the $h_1(x)$ and $h_2(t)$ functions that compose $h(x,t)$. The input stimulus moves almost diagonally across the (x,t) plane, such that equal contributions to the surface $g(x,t)$ come from both time and space. By examining these surfaces, it is not only possible to predict quantitative blur lengths but also interpret qualitative descriptions given by experimental subjects.

In addition to quantitative results, Matin's subjects also gave qualitative discriptions of their observations following experimental trials. In several cases, they reported the slit to appear shifted from its final position. Experimentally, this occurred with light durations of approximately 27 msec. The same phenomenon can be observed in the projections of $g_1(x)$ (Figure 6 D & E). In this case, a duration of 27.5 msec begins to show a peak forming at the left side close to where the peak from the slit will eventually appear. At a duration of 32.5 msec, we see two peaks at the left side. However, the far left one now dominates. With a contrast rule applied, this will be the final perceived slit location. Thus, the perceived location of the slit in the model occurs as reported during the experiment. Furthermore, note the deep valley that forms between the slit peak and the "blur" to the right. This is in qualitative agreement with experimental descriptions of a blur and slit with a gap in between them as the slit begins to appear.

The model's retinal response is computed from spatial and temporal response data taken from an entirely different context (Wilson, 1976, Cornsweet, 1970). It is certain that Matin's subjects had different temporal and spatial responses. Nevertheless, the model results are accurate in predicting the overall experimental findings. Furthermore,

it is expected that predictions would improve with a more precise h(x,t) function to account for individual differences.

References

Arend, L., "Temporal Determinants of the Spatial Contrast Threshold MTF," Vis. Res., 16, 1035-1042, 1976.

Bridgeman, B., "Reply to Brooks and Fuchs: Exogenous and Endogenous Contributions to Saccadic Suppression: Vis Res, 17, 323-324, 1977.

Brooks, B., Fuchs, A., "Influence of Stimulus Parameters on Visual Sensitivity During Saccadic Eye Movements," Vis. Res., 15, 1389-1398.

Cornsweet, N. "Visual Perception," Academic Press, 1970.

Furchner, C., Thomas, J., Campbell, F., "Detection and Discrimination of Simple and Complex Patterns at Low Spatial Frequencies," Vis. Res., 17, 827-836.

Glezer, V.D., Gauzelman, V., Tsherbach, T., Dudkin, K., "Comments on Organization and Spatial-Frequency Characteristics of Receptive Fields in the Visual Cortex," Vis. Res., 18, 887-889, 1978.

Grunau, M., "Interaction between Sustained and Transient Channels: Form Inhibits Motion in the Human Visual System," Vis. Res., 18, 197-201, 1978.

Hines, M., "Line Spread Function Variation Near the Fovea," Vis. Res., 16, 567-572, 1976.

Legge, G., "Sapce Domain Properties of a Spatial Frequency Channel in Human Vision: Vis. Res., 18, 959-969, 1978.

Mackay, D., "Elevation of Visual Threshold by Displacement of Retinal Image," Nature, 225, 90-92, 1970.

Matin, E., "Saccadic Suppression: A Review and an Analysis," Psychol., Bull., 81, 899-917, 1974.

Matin, E., Clymer, A., Matin, L., "MetaContrast and Saccadic Suppression, Science, 178, 179-182.

Matin, L., "A possible hybrid mechanism for modification of visual direction associated with eye movements - The Paralyzed Eye Experiment Reconsidered," Perception, 5, 233-239, 1976.

Matin, L., Matin, E., "Visual Perception of Direction and Voluntary Saccadic Eye Movements." Biblio. Ophthal, 82, 358-368, 1976.

Matin, L., "Eye Movements and Perceived Visual Direction, "Handbook of Sensory Physiology, 8, Visual Psychophysics, 332-380, 1972.

Mitrani, L., Radil-Weiss, T., Yakimoff, N., Mateeff, S., Bozkov, V., "Determination of Vision Due to Contour Shift Over the Retina During Eye Movements," Vis. Res., 15 877-878, 1975.

Ohley, W.J., Kao, C., Jaron, D., Validity of an Arterial System Model: A Quantitative Evaluation, IEEE Trans. On Biomedical Engineering BME, 1980.

Ohley, W.J., "A Computer Model of Saccadic Suppression," USAF Mini Grant Program Final Report, 1979.

Sakitt, B., "Information Received from Unseen Lights," Vis. Res., 16, 782-784, 1976.

Shebilske, W., "Extra Retinal Information in Corrective Saccades and Inflow vs. Outflow Theories of Visual Direction Constancy," Vis. Res., 16, 621-628, 1976.

Spitzberg, R., Richards, W., "Broad Band Spatial Filters in the Human Visual System," Vis. Res., 15, 837-841, 1975.

Stark, L., Kong, R., Schwartz, S., Hendry, D., Bridgemen, B., "Saccadic Suppression of Image Displacement," Vis. Res., 16, 1185-1187, 1976.

Volkman, F., Riggs, L., White, K., Moore, R., "Contrast Sensitivity During Saccadic Eye Movements, : Vis Res., 18, 1193-1199, 1978.

Wilson, H., Phillips, G., Bentschlen, I., Hilz, R., "Spatial Probability Summation and Disinhibition in Psycholophysically Measured Line Spread Functions," Vis. Res., 19, 593-598, 1979.

Wilson, H., "Quantitative Charracterization of Two Types of Line Spread Function Near the Fovea: Vis. Res., 18, 971-981, 1978.

Yarbus, A., "Eye Movements and Vision," Plenum Press, 1967.

Figure Captions

Figure 1. Two-dimensional impulse response of the retina

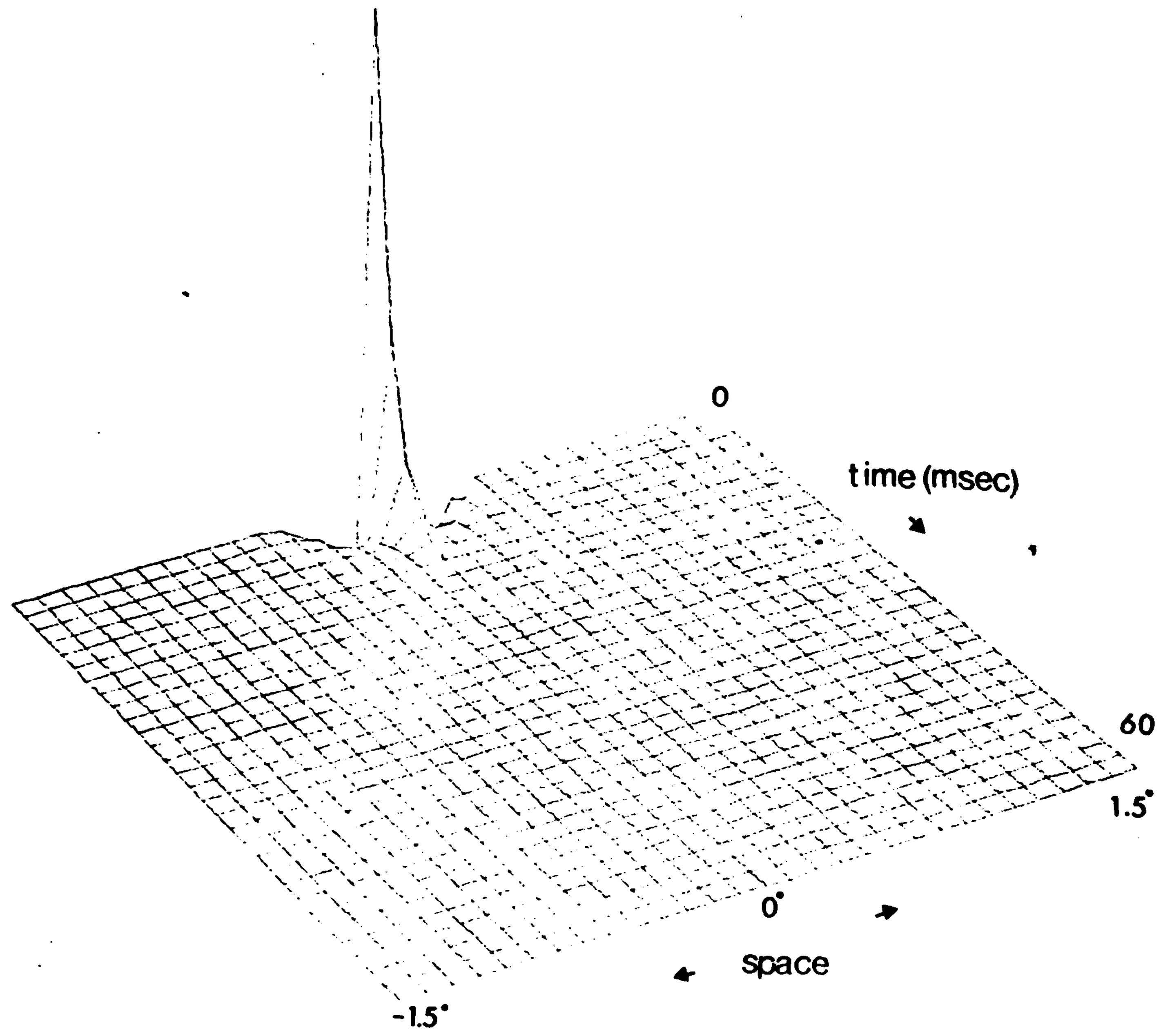
Figure 2. Results of Matin's saccadic suppression experiment

Figure 3. Response function $g(x,t)$ produced by the model for a short duration slit

Figure 4. Response function $g(x,t)$ produced by the model for a long duration slit

Figure 5. Sequence of the spatial projection $g_t(x)$ for slit durations of 17.5 to 83 msec. Amplitude units are arbitrary and normalized. Note the "blur length" increasing from A to C. In D and E the peak caused by the slit begins to appear and is fully developed in G.

Figure 6. Model results plotted in same form as Matin's data (Fig. 2).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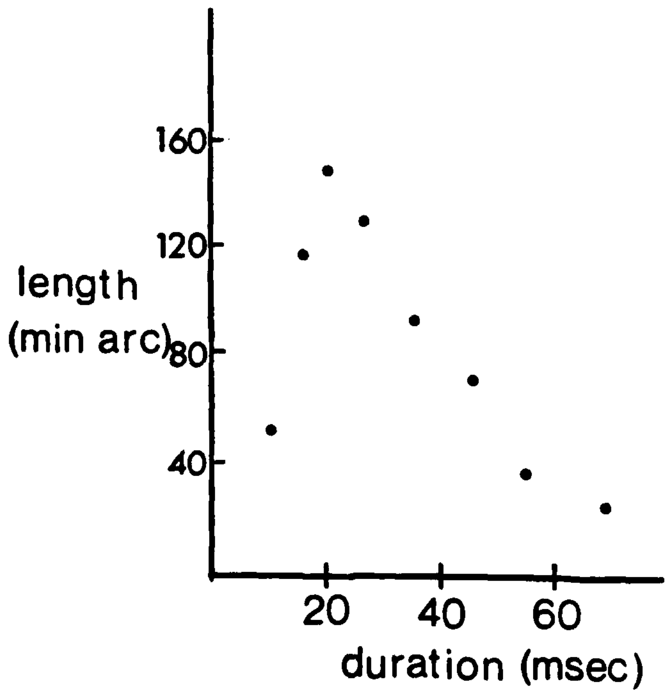
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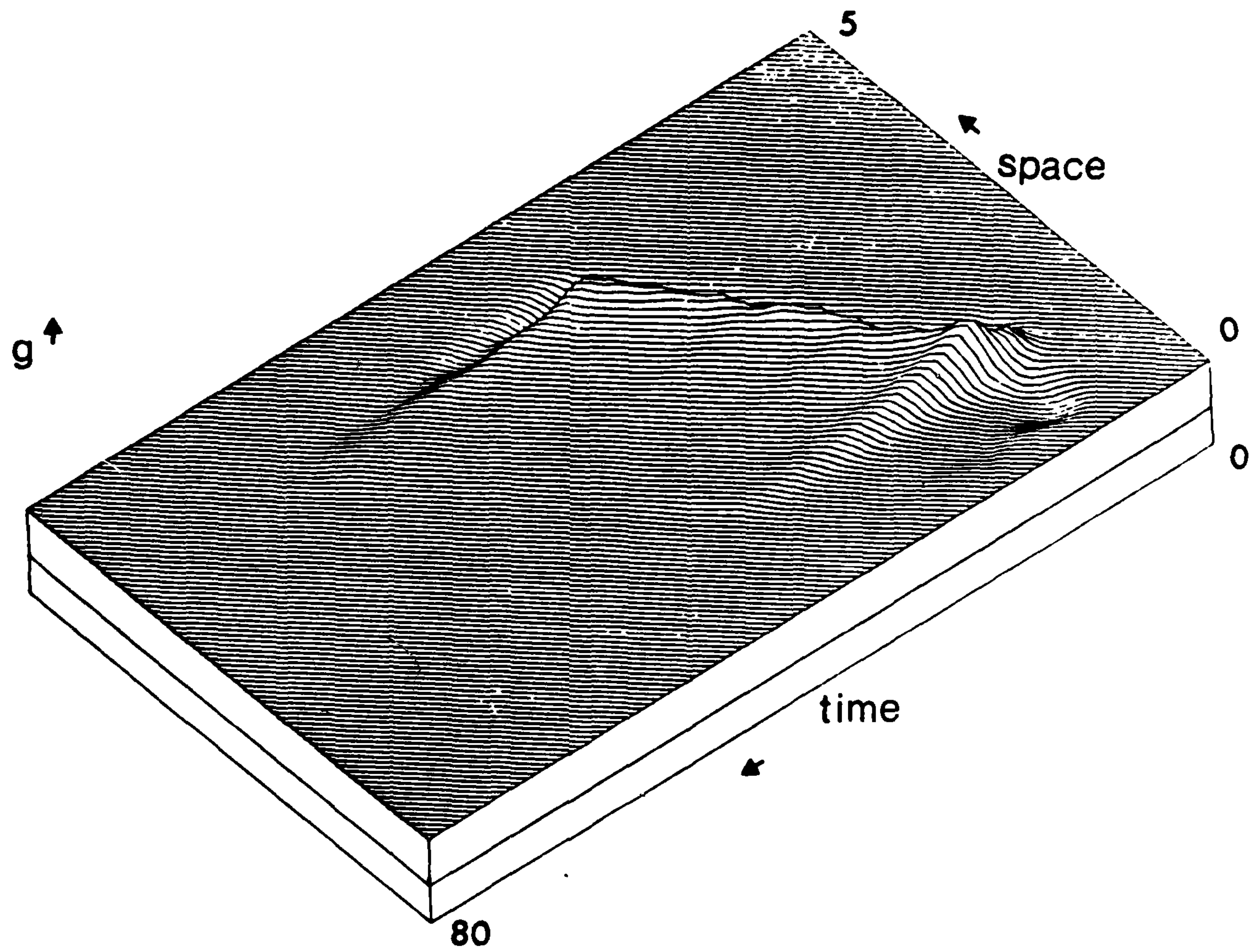

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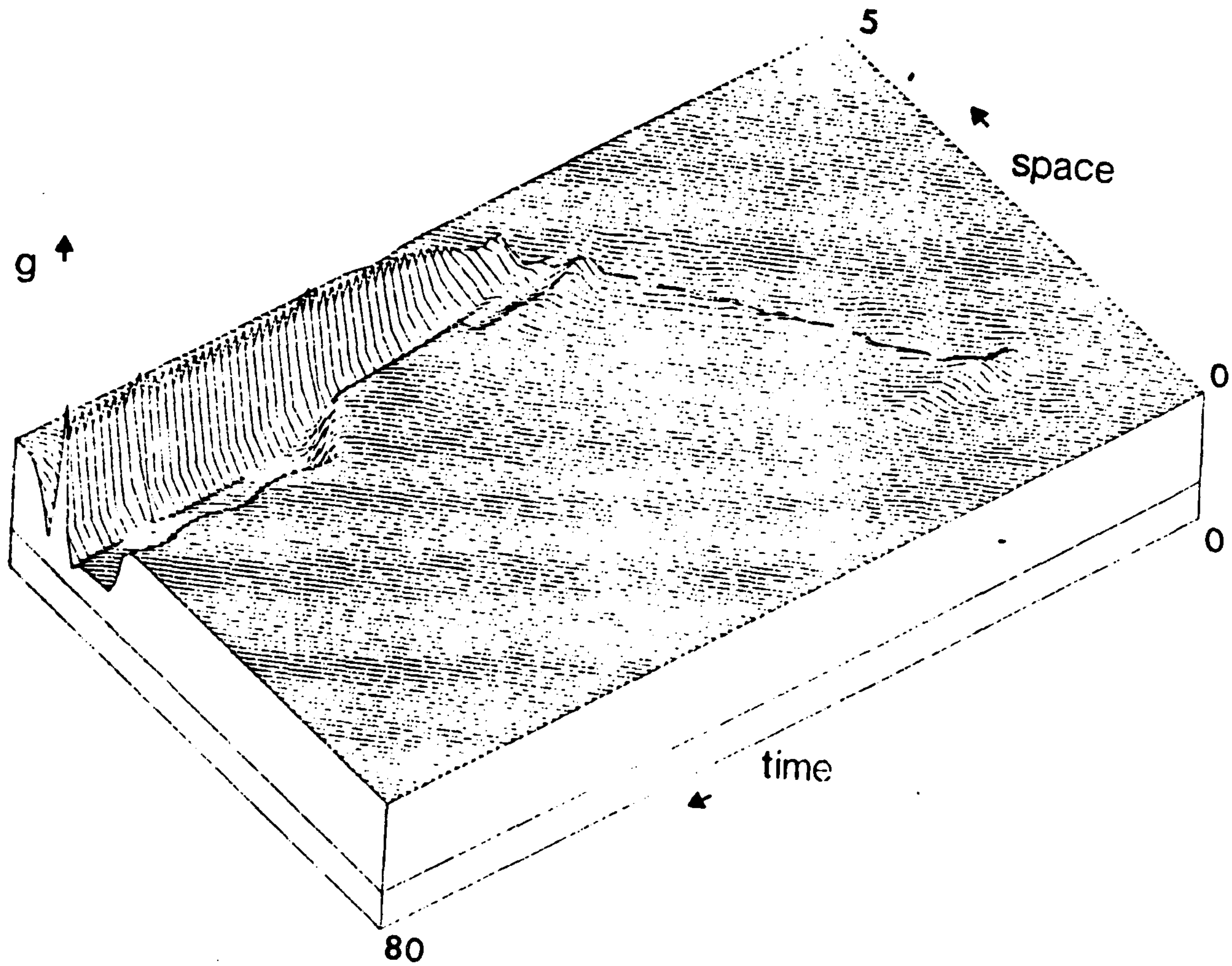
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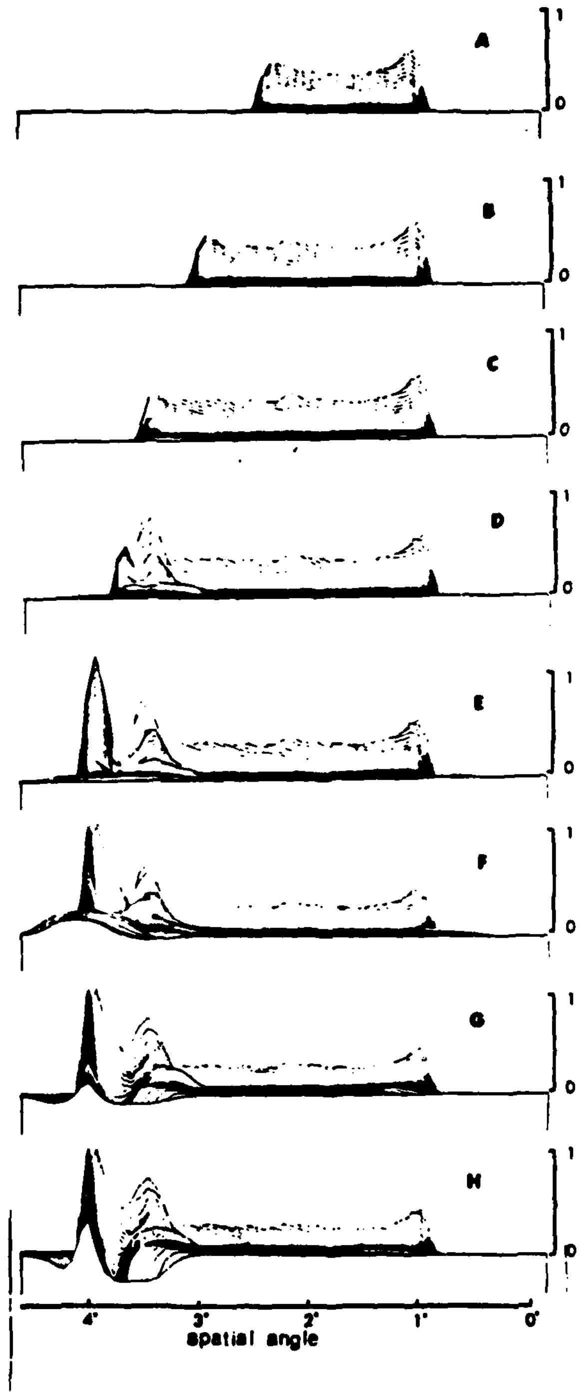
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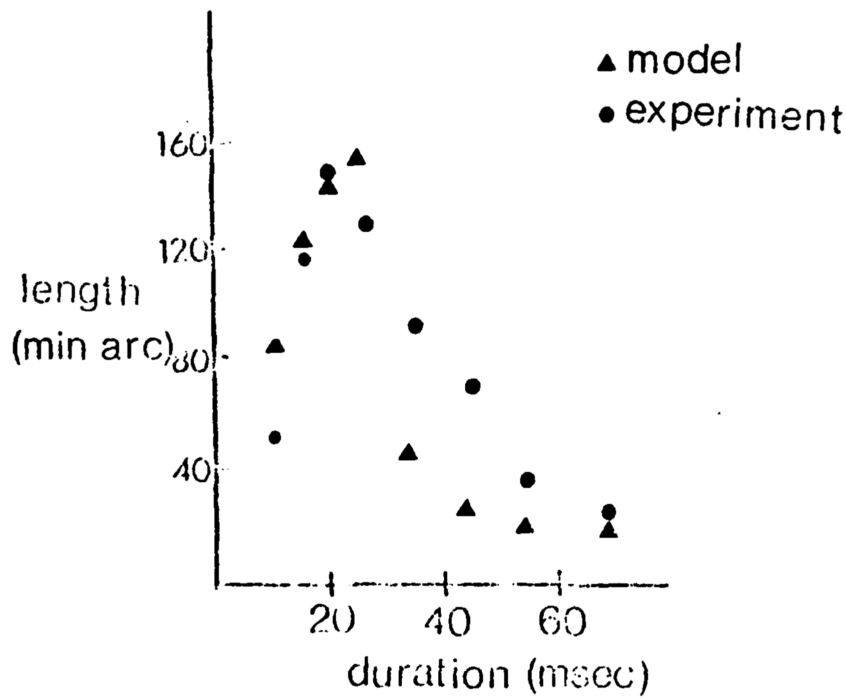

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CLUTTERED DISPLAYS: AN EXPERIMENTAL AND
COMPUTER MODELING APPROACH

A proposal submitted by William J. Ohley and Charles Collyer)

ABSTRACT

Display clutter can limit a pilot's ability to process information from visual display devices such as HUDs (heads-up-display). Masking of information, distraction of attention, and inappropriate response execution, represent potentially costly effects of clutter, and sources of pilot error. This project proposes procedures for distinguishing among alternative effects of display clutter, in two kinds of information processing task. Both psychophysical and eye movement data will be collected from human subjects. Computer simulation of the visual response to clutter, will be compared with these behavioral data. Thus, the investigation of clutter effects comprises complimentary experimental and computer modeling approaches. The overall goal of the project is to develop a useful theory of display clutter, separating different effects on different tasks according to their source and level of effect on processing. Such a theory can be used to guide future display design in the direction of error reduction.

CLUTTERED DISPLAYS: AN EXPERIMENTAL AND
COMPUTER MODELING APPROACH

I. Introduction

The pilot of a modern fighter aircraft engaged in high-speed, low-altitude execution of an attack mission, represents very nearly the maximum demand that can be placed on human information processing. This situation is one of high stress, rapidly changing informational inputs, short response times, and narrow tolerances at several different levels of performance. Errors of perception, judgment, or response execution are costly in the extreme. Restricting attention to visual aspects of this situation, let us ask how such errors may arise, how they may be analyzed, and how they can be minimized.

Modern aircraft are equipped with numerous sensors and analyzing instruments that feed information to the pilot in a visually displayed form. Extracting critical information from such displays is made difficult by the rapidity with which events change, and by the sheer number of different pieces of information. Display clutter can be a major obstacle to efficient visual processing.

What effects might be produced by visual clutter? One possibility is masking of one piece of information by another. Masking refers to a reduction in the sensory signal-to-noise ratio of the information in the sensory signal-to-noise ratio of the information that is to be processsed. Another possibility is visual distraction of attention. Distraction refers to a rapid re-allocation of attention, for example, away from the target information, and toward the distracting stimulus. A third possibility is response error. Response error refers to the pilot executing a response triggered by some part of the clutter, rather than by the appropriate target information.

These three sources of error are not always mutually exclusive. In this proposal, however, by applying an experimental and mathematical modeling approach, we will show that masking, distraction, and response error are separately identifiable in certain visual situations closely analogous to cluttered HUD or CRT displays. Furthermore, the course of action to be taken in order to minimize the error, will depend on whether masking, distraction, or response error has been identified as the error's source.

II. Background

In real life, it is rare to find perceptual tasks peformed in "clean" environments, where only the stimuli to be processed are presented, and in which extraneous clutter is controlled. In laboratory research on perception, however, "clean" environments are the rule; thus most existing data does not address the clutter problem. One notable exception is masking research, in which the interfering effects of one stimulus on another, are the phenomena of interest. However, masking studies do not often provide ways of distinguishing masking effects from other sorces of perceptual error. Because the effects of task-irrelevant clutter have not been emphasized in past research, we shall not present an extensive literature review as background to this project proposal. Our own previous work does constitute relevant background, and will be outlined in this section. Some references to relevant work by others will be noted in later sections.

Collyer (1976) attempted to bridge the gap between clean and cluttered perceptual situations, by asking observers to perform a temporal order judgment (TOJ) task while viewing a deliberately cluttered display. The clutter consisted of two "inducing" lights (A and B in Figure

1), which were illuminated at the beginning of an experimental trial, and were turned off just prior to the presentation of the two test lights (C and D in Figure 1). It was found that the order of offset of the inducing lights strongly influenced observers' judgments of the onset order of the test lights. This Induced Asynchrony Effect (IAE) is powerful enough to be visible on viewing single trials -- it is more than a small statistical artifact. The test light on the same side of the display as the first clutter offset, seems to come on sooner than the other test light, when physically the onsets are simultaneous (hence the term induced asynchrony). Figure 2 summarizes a large amount of data collected from three observers, and shows that this effect of clutter on time jugdments is substantial; different patterns of clutter produce changes in behavior comparable to those produced by the task variable of onset order.

Could the IAE be attributable to response error? That is, could the observer be responding to the offset order of the inducing lights rather than to the onset order of the test lights? The answer is no. Collyer (1976) argued that response error would reduce the slopes of the top and bottom curves in Figure 2, relative to the middle curve. Since the three curves are almot perfectly parallel, the response error possibility was rejected.

The IAE could be due either to masking or to distraction. Recent work has focussed on testing these competing interpretations of the effect. The masking hypothesis is that lights A and B (the clutter) exert a lateral inhibitory effect on the subsequent test lights (this would be termed paracontrast in the masking literature). Further, the masking effect is hypothesized to be inversely related to the time interval between inducing and test lights. the IAE would then arise

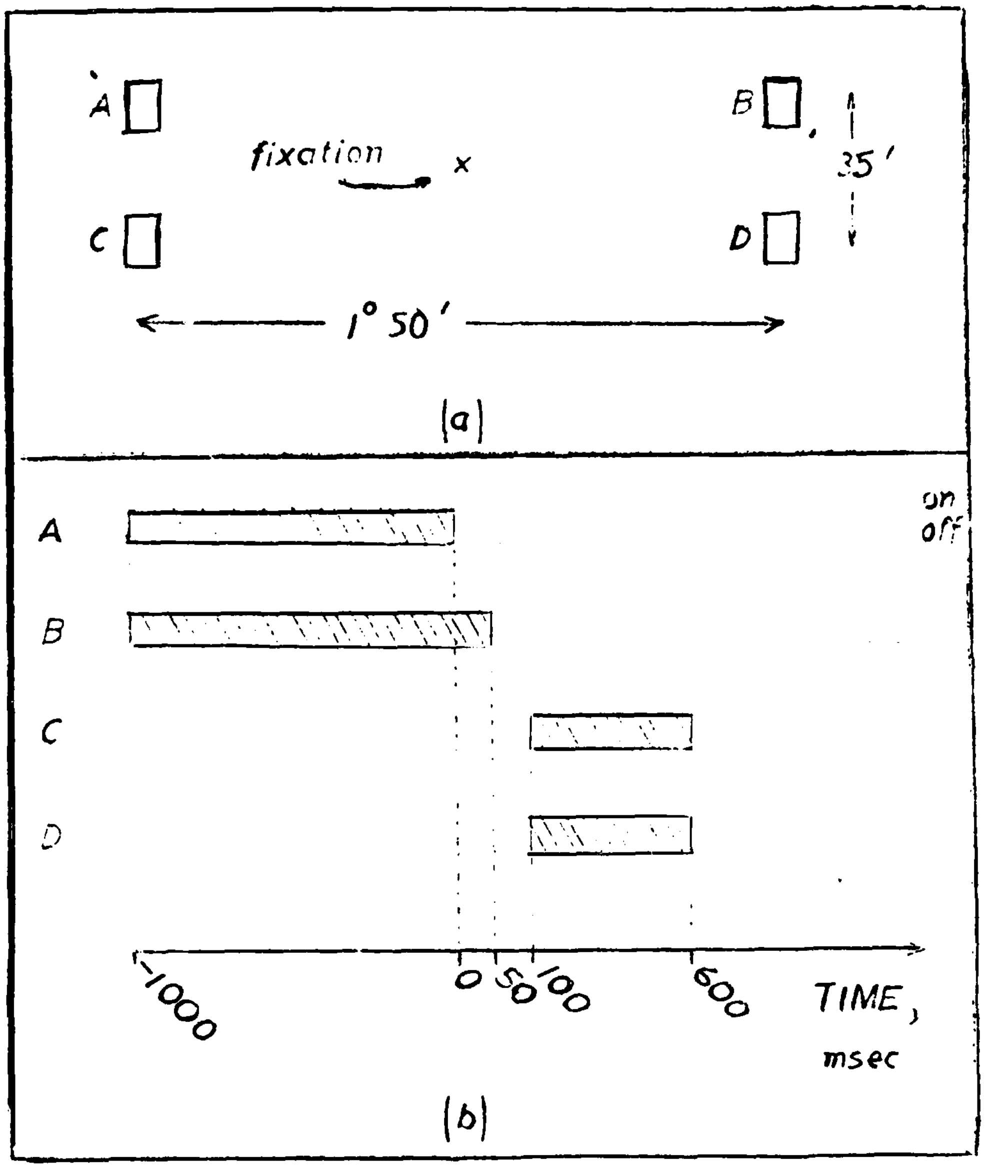

Figure 1. Conditions for the Induced Asynchrony Effect (IAE):
(a) Spatial configuration of lights. (b) Time course of lights in trial type (A,B; C=D).

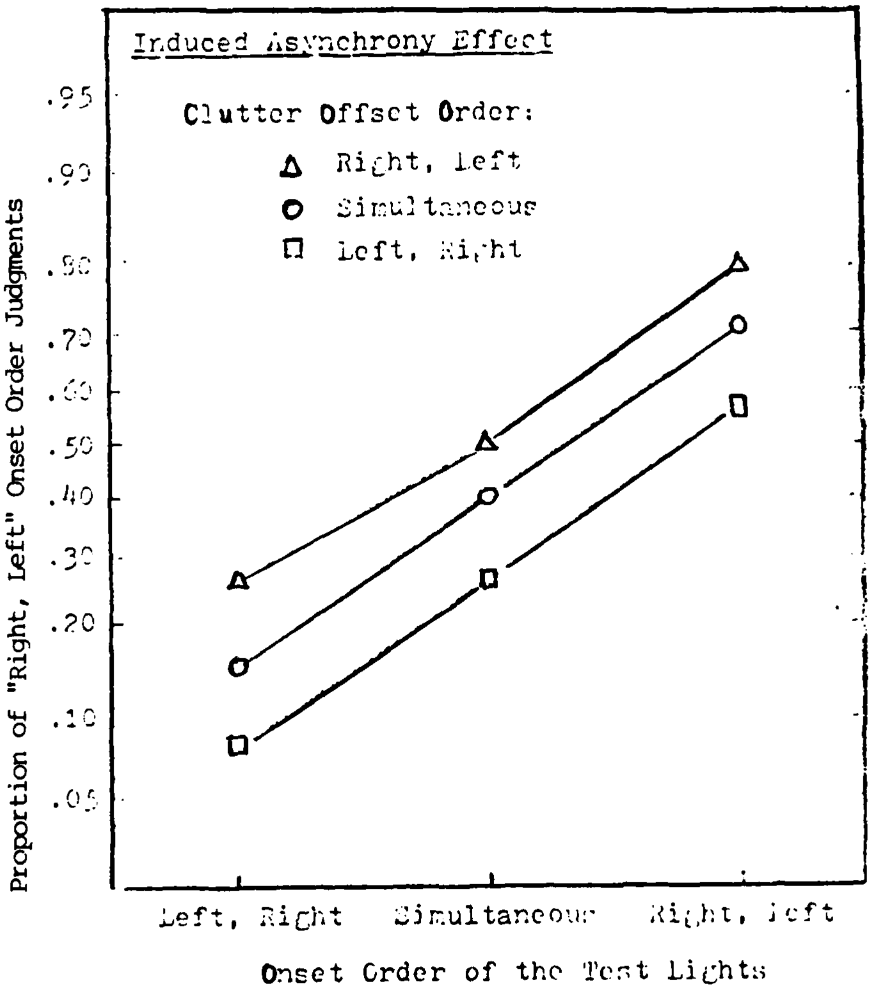

Figure 2. The Induced Asynchrony Effect (IAE). The effect of the clutter variable is to shift the psychometric function for temporal order judgments. Each data point is based on 495 judgments (165 by each of three observers). (After Collyer, 1976).

from the earlier release from inhibition of the test light closest to the first inducer offset. (For reviews of masking and related phenomena see Kahneman, 1968; Breitmeyer and Ganz, 1976).

The distraction hypothesis is that the first inducer offset initiates a reflexive, covert shift of attention away from central fixation and toward the distracting event. Processing of the test stimulus on the side to which attention has shifted is then facilitated, resulting in earlier perception of its onset. (For brief treatments of related hypotheses, see Jonides, 1976; Klein 1978; Breitmeyer & Gantz, 1976).

An experiment has recently been carried out to provide one test of these hypotheses. Brief flashes of light positioned at A or B, rather than long-duration lights, preceded the test stimuli on some trials. The flashes were produced by simply removing the 1000 msec concurrent illumination at A and B (refer to Figure 1). Thus, the onset-to-offset duration of the flashes corresponds to the offset asynchrony of the two inducing lights in the original condition.

The masking hypothesis predicts that a flash will exert some inhibitory effect on the closest test light, while the test light on the other side of fixation should be relatively unaffected. The flash, in other words, should play roughly the same role in this condition as did the second inducer offset in the original stimulus pattern from which it was generated. Thus, the masking hypothesis predicts that the IAE should be obtained in the flash experiment, in its original form; flashes to the right should induce more "left, right" onset order responses, and conversely.

The distraction hypothesis predicts that the flash will attract the observer's attention, resulting in a facilitation of the closest test-light. In the flash condition, the directionally specific distracting

event is no longer the first inducer offset, but the onset of the flash (which occurs at the same relative time, but on the other side of the display). Thus, the distraction hypothesis predicts that the IAE should reverse its directionality in this condition: flashes to the right should induce more "right, left" onset order responses, and conversely.

Figure 3 shows the results of the flash experiment, for two observers whose data have been probit-averaged. The flash manipulation had a substantial effect on observers' temporal order judgments, resulting in a reversed IAE, and supporting the distraction hypothesis. Both observers had also run in a replication of the original IAE condition, and had reproduced the 1976 result. The non-parallel functions of Figure 3 suggest that distraction is compounded by response error in the flash condition. There were indications in the data from two further observers of individual differences in susceptibility to distraction by asynchronous offsets; however, distraction by flashes seems at this point to be obtainable for all subjects, with varying admixtures of response error.

The example of the IAE illustrates that it is possible to analyze the effects of display clutter experimentally. We propose to extend this experimental approach to the analysis of tasks in which clutter complicates the processing of stimulus energy and symbolic information, of the sort displayed to pilots via HUD or CRT displays.

The experimental approach is complemented by a modelling approach developed originally by Ohley (1979) while a summer faculty fellow at AFHRL, Wright Patterson AFB, Ohio. The model was further refined under the AFOSR mini-grant program. In this approach known sensory properties of the visual system, i.e., the Line Spread Function (LSF) and temporal response function (TRF) are mathematically combined. A specific retinal

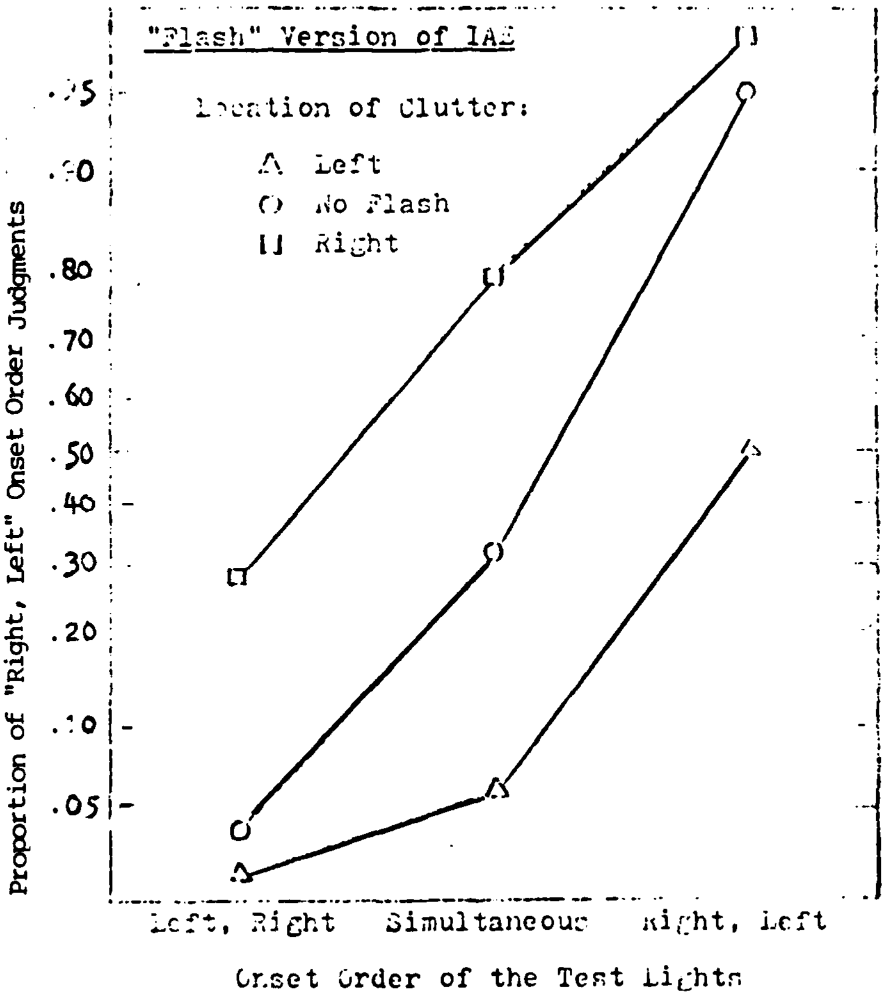

Figure 3. Results of an experiment using brief flashes as clutter stimuli. The ordering of the three curves supports a distraction interpretation of the IAE, and is inconsistent with a masking interpretation. Each data point is based on 200 observations.

stimulus described as a function of time and space is used as input to the model. The model then provides in a three-dimensional computer graphics display a simulation of visual information provided to the cortex.

The modeling of initial sensory response to a cluttered display can provide another route to distinguishing among masking, distraction, and response error. Further, theoretical interpretations of performance effects can be addressed from both the experimental and from the modeling approaches; inconsistencies of interpretation can be quickly spotted, and agreement of the two approaches can result in more complete theory development. For example, the model may show that for two types of stimuli the same or similar stimulus pattern reaches the visual cortex. However, in disagreement with the model, the experimental results may show two distinct responses. Thus, we could directly conclude that there are more important higher level functions occurring in that situation. On the other hand if the model does predict responses accurately, it can immediately lead to a mathematical theory of visual response to clutter.

The results of any model rely heavily on its validity. Ohley has had experience with testing the validity of high order mathematical models (Ohley, 1980). How good is the computer model of retinal activation? Ohley (1979) has applied the model to data on saccadic suppression, with good success. Figure 4 illustrates the model's graphic output, the figure plots retinal activation evoked by a brief slit of light presented during and after a voluntary saccadic eye movement. The deep "trough" adjacent to the highest peaks of the graph, depicts a type of lateral inhibition which in turn provides a good account of saccadic suppression. Figure 5 compares the behavior of the model at various

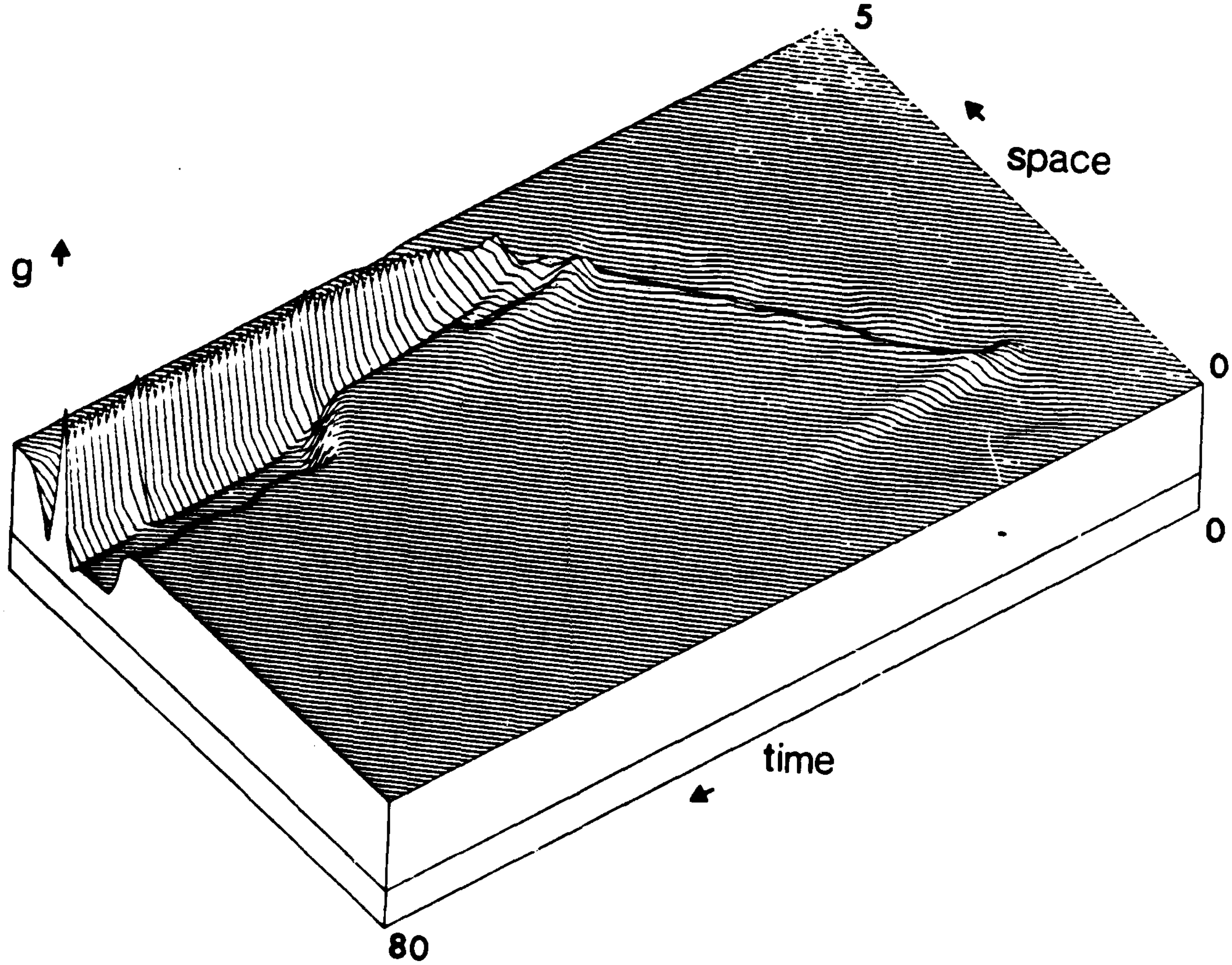

Figure 4.

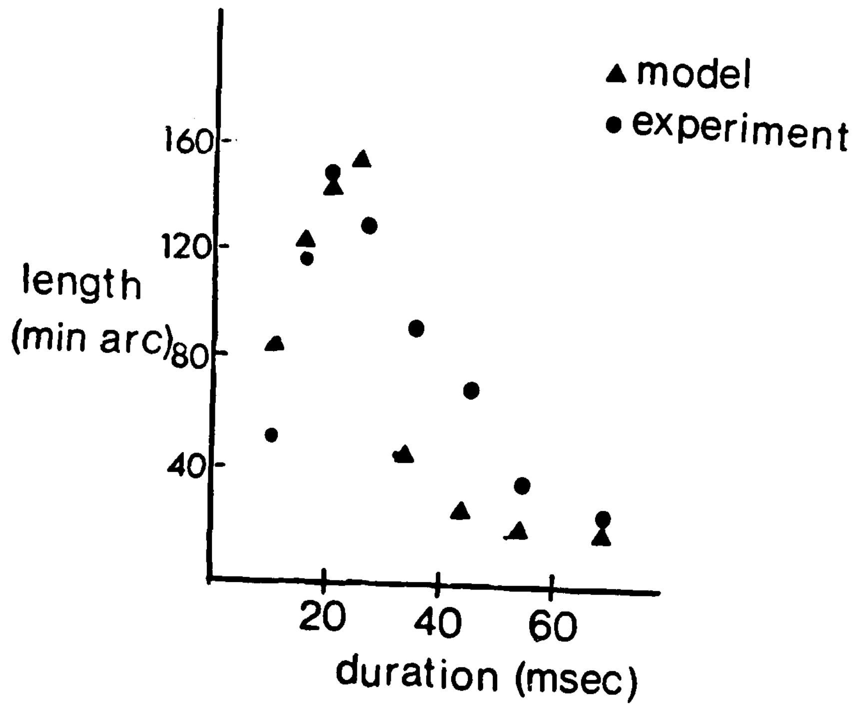
model
experiment
160
120
80
40
length
(min arc)
20
40
60
duration (msec)

Figure 5.

slit durations to data collected by Matin (1972) on saccadic suppression, and shows that the model explains this data rather well. The essence of the model is that it considers the spatial and temporal sensory response characteristics in a combined form, thus allowing for the interaction of both effects. This combination is especially critical when retinal stimuli are characterized by rapidly changing time and spatial conditions - such as in our proposed experiments and in combat situations. The model can accept a wide variety of inputs specifying different stimulus patterns, including those of cluttered displays. A complete model description, including the theoretical assumptions are developed in Part I., "A Sensory Model of Saccadic Suppression."

III. Specific Aims

A combined experimental and modelling approach will be brought to bear on the problem of display clutter. Specific aims of the project can be organized under the headings Processing of Energy and Processing of Symbols. These refer to luminance - increment detection and alphaumeric character recognition tasks respectively. For each of these levels of information procesing, the aims are:

a. Experimental analysis of clutter effects on the processing of information changes; identification of the origin of such effects (masking, distraction, response error); correlation of such effects with clutter-induced eye movements.

b. Modelling analysis of these effects to determine the relative significance of sensory mechanisms and decision mechanisms contributing to task performance. Inputs to the computer model will

be defined both by the stimulus patterns used in the psychophysical experiments, and by the empirically-determined eye movement responses of the observer.

An integrative aim of the studies is to determine the extent to which clutter effects on symbolic information processing can be accounted for by the effects on processing of energy information.

IV. Methods

A. Overview of the Project

We plan to study clutter effects on two kinds of information processing: detection of luminance changes, and recognition of alphanumeric symbols. One goal is to determine whether clutter effects can be attributed to simple sensory processes, or involve higher-order cognitive processes. Our study of luminance-increment discrimination will provide data on the kind and degree of clutter's influence on pre-symbolic sensory judgments of sheer stimulus energy. It may or may not be the case that effects on symbol recognition will be adequately accounted for by clutter effects at lower levels of processing. Answering this question will contribute to the development of a useful theory of display clutter to guide future display design in the direction of error reduction.

The choice of clutter stimuli to be studied is an important first decision. Rather than attempt to simulate visual displays such as HUD's in their full complexity, we will initially employ clutter stimuli similar to those that Collyer has shown to influence temporal judgments. These flash and/or offset display events have the virtues of being simple to specify and control, and of lending themselves to experimental designs in which masking, distraction, and response error can be distinguished. Further, these clutter stimuli are sufficiently similar to HUD stimuli to

protect the relevance of the research to applied error-analysis problems.

Stimuli will be presented on a computer-controlled CRT display for both the luminance and the symbolic tasks; the luminance task will be cross-validated using a computer-controlled light-emitting diode (LED) display as well, in order to take advantage of the precision of photometric and temporal specification, and the larger visual angles made possible by this type of display.

Target and clutter stimuli will initially be arrayed along one (horizontal) display dimension. Horizontal eye movements will be recorded during the experiments, using a limbus-tracking technique. The uni-dimensional display, and spatio-temporal information about clutter-induced eye movements, will facilitate specification of the input to the computer model. In this stage of the project, we will restrict our theoretical analysis with the model to 3 dimensions: space, time, and luminance. Thus, the model in its present form can be directly applied to assess the sensory response to a stimulus.

In the experimental work on character recognition, because symbols are generally two dimensional, it will be necessary to monitor eye movements in both spatial dimensions. To interpret this experimental data, the model will be expanded into 4 dimensions: horizontal space, vertical space, time, and luminance.

Psychophysical tasks will involve monitoring of two target positions on the display. Dual-target monitoring is considered superior to single-target monitoring for two reasons: First, it is the rule rather than the exception that pilots must monitor multiple sources of information. Second, dual-target monitoring can be analyzed using powerful dual-task attention-operating-characteristic methods (Kinchla, 1977, 1978; Navon &

Gopher, 1979; Sperling & Melchner, 1978a, 1978b) which provide information on the subject's allocation of attention. Two versions of the dual-target monitoring task will be used, termed whole report and partial report. The advantages of, and the differences between, these versions of the task, are described in the following sections.

B. Processing of Energy: Luminance-Increment Detection

Changes in the luminance of an instrument indicator can signal information to the pilot or instrument operator. Such changes range from a light turning on and off normally to momentary flickering of a whole screen or panel. Clutter stimuli themselves may also consist of luminance or energy changes. In this study, we are concerned with interference between one source of energy variation (clutter) and the processing of another source of energy variation (the luminance levels of two target lights monitored by the subject). The goal of this part of the project is to assess and interpret clutter effects on the detection of luminance changes.

During an observation interval, each of the target lights that may or may not be incremented in luminance independently. Target patterns may then be indexed 00, 01, 10, and 11, where a 0 denotes no increment, a 1 denotes an increment, and the left and right numerals refer to the left and right target lights respectively.

In whole report, the subject is required to monitor the two target lights under varying conditions of preceding clutter, and to respond by indicating for both lights, whether or not increments occurred. Clutter-by-target pattern stimulus conditions for this task are shown in Table 1. Sixteen conditions are defined by independently combining increment/no increment for each of the two target lights, with clutter/no clutter for

left and right positions of the clutter stimuli. (Clutter will consist of flashes in the left and/or right periphery). Two yes/no responses would be made for each observation, indicating the subject's detection judgments for the two target lights. Detection accuracy (d') as a function of clutter condition for each target light, would be the main data of interest. The spatial separation of the target lights in the display would be varied in order to manipulate the difficulty of the monitoring task.

One possible pattern of results is shown in Figure 6 to illustrate the type of information that might be gained from this study. The pattern shown suggests a facilitative effect of clutter on the detection of increments in the luminance of the target nearest to the clutter, at the expense of performance on the other target. The equivalence of no-clutter and double (left-&-right) clutter in this example would suggest that the sheer presence of task-irrelevant stimuli does not influence processing of energy changes in the targets; rather it is the directional specificity of clutter (left or right) that affects performance. This example would point to a distraction interpretation rather than a masking interpretation.

In partial report, the subject only makes one yes/no response per observation, instead of two. The subject would be cueo following the target pattern as to which of the two targets to report. A sample design for this task is shown in Table 2. Thirty-two conditions are defined, corresponding to the cue-by-clutter-by-target pattern combinations.

The partial report task differs from the whole report task in that the subject is instructed by the cue to ignore some of the information that has already been monitored and processsd. Thus, in addition to providing accuracy scores for cued information (which can be compared to

Table 1

Conditions (jklm) defined by clutter and target patterns, in whole report dual-task monitoring.

No Clutter (jk=00)

		Right Target	
		m = 0	m = 1
Left Target	l = 0	r_{0000}	r_{0001}
	l = 1	r_{0010}	r_{0011}

Right Clutter (jk=01)

r_{0100}	r_{0101}
r_{0110}	r_{0111}

Left Clutter (jk=10)

r_{1000}	r_{1001}
r_{1010}	r_{1011}

Right and Left Clutter (jk=11)

r_{1100}	r_{1101}
r_{1110}	r_{1111}

*Note: The data, r_{jklm}, consists of pairs of "yes" response proportions, as whole report requires judgments of both target positions.

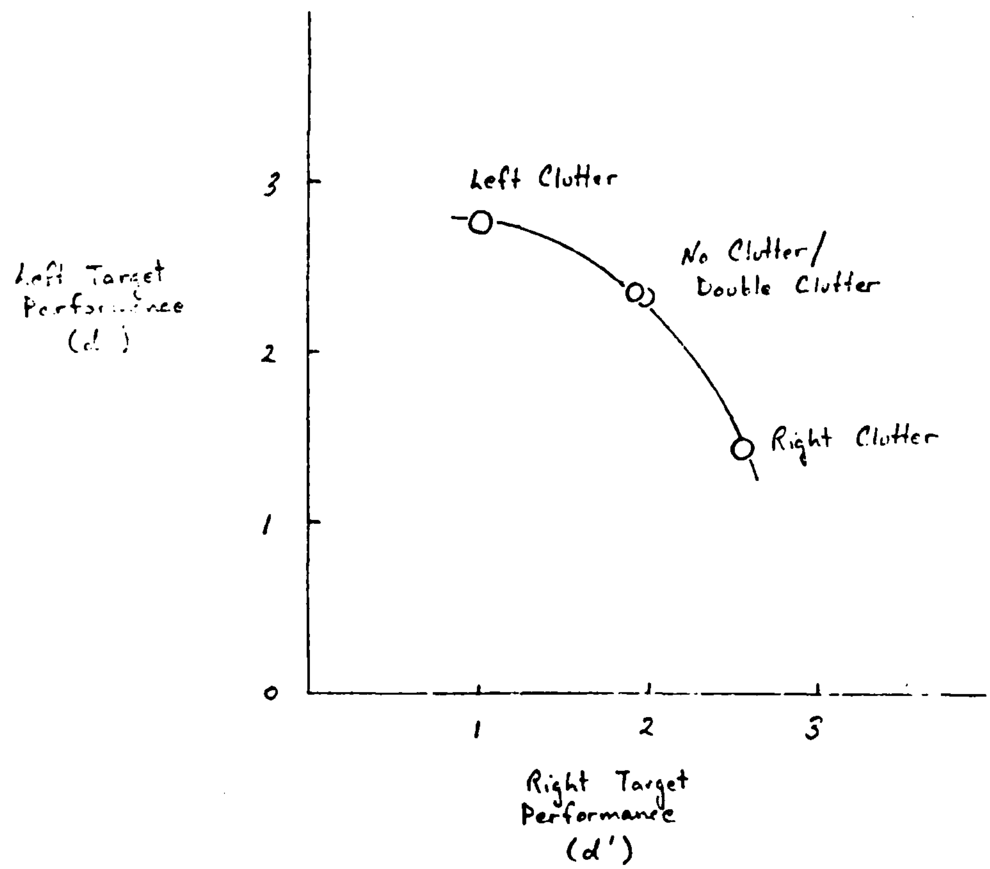

Figure 6. One possible of whole report luminance increment detection data; attention operating characteristic representation.

Table 2

Conditions (ijklm) defined by position cued, clutter, and target patterns, in partial report dual-target

Left Target Cued (i=0)	Right Target Cued (i=1)
No Clutter (jk=00)	
Target Patterns (lm=)	
(lm=00); z_{00000}*	z_{10000}
(lm=01); z_{00001}	z_{10001}
(lm=10); z_{00010}	z_{10010}
(lm=11); z_{00011}	z_{10011}
Right Clutter (jk=01)	
Target Patterns (lm=)	
(lm=00); z_{00100}	z_{10100}
(lm=01); z_{00101}	z_{10101}
(lm=01); z_{00110}	z_{10110}
(lm=11); z_{00111}	z_{10111}
Left Clutter (jk=10)	
Target Patterns (lm=)	
(lm=00); z_{01000}	z_{11000}
(lm=01); z_{01001}	z_{11001}
(lm=10); z_{01010}	z_{11010}
(lm=11); z_{01011}	z_{11011}
Right and Left Clutter (jk=11)	
Target Patterns (lm=)	
(lm=00); z_{01100}	z_{11100}
(lm=01); z_{01101}	z_{11101}
(lm=10); z_{01110}	z_{11110}
(lm=11); z_{01111}	z_{11111}

*Note: The data, z_{ijklm}, consist of z-transformed proportions of "yes" responses under each cue-clutter-target condition.

whole report performance), the partial report task allows us to assess the subject's ability to successfully exclude the non-cued information from the judgment.

The effects of luminance increments on responding can be measured using d'-like discrimination scores, computed as follows (refer to Table 2 for a guide to the subscripts):

Effect of left increment when left position is cued:

$$D_{c,0jk} = 1/2(z_{0jk00} + z_{0jk01}) - 1/2(z_{0jk10} + z_{0jk11}),$$

for each clutter condition (jk). Similarly,

Effect of right increment when left position is cued:

$$D_{n,0jk} = 1/2(z_{0jk00} + z_{0jk10} - 1/2(z_{0jk01} + z_{1jk11}).$$

Effect of left increment when right position is cued:

$$D_{n,1jk} = 1/2(z_{1jk00} + z_{1jk01}) - 1/2(z_{1jk10} + z_{1jk11}).$$

Effect of right increment when right position is cued:

$$D_{c,1jk} = 1/2(z_{1jk00} + z_{1jk10}) - 1/2(z_{1jk01} + z_{1jk11}).$$

(In the first and fourth equations, the subscript "c" denotes that the score measures the effect of a cued increment; in the second and third, the subscript "n" denotes that the score measures the effect of a non-cued increment).

The effects of non-cued increments may be regarded as a species of response error, resulting from the subject's strategy for handling to-be-ignored information. For example, if $D_{n,0jk}$ were significantly less than zero, this would indicate that the <u>presence</u> of a to-be-ignored increment in the right target position makes the subject <u>less</u> likely to report an increment in the cued left position. Such an effect might result from masking, or from a strategy of "bending over backwards" by the subject to reject non-cued but already-processed information from the decision process. Another possibility is that increment in either target

position mask the other position. Thus the presence of a non-cued increment might make subjects less likely to detect cued increments. This possibility could be tested in luminance decrement detection task, run as a control condition. If masking of one target by the other, or non optimal strategies are present in pilots' information processing decisions, they could constitute significant sources of error. Further, if such effects are potentiated by the current clutter pattern, there may be either a simple or a complex form to this interaction. One advantage of the partial report design is that it provides a means of uncovering and classifying such effects and interactions.

Figure 7 shows an attention-operating-characteristic (AOC) space for a hypothetical set of partial report data. This data is fictitious, and is presented simply to illustrate some inferences that can be made from the AOC representation. The axes of the graph represent discrimination scores for the right and left cueing conditions. A point in the space represents a pair of discrimination scores, for these two cueing conditions under one clutter condition. The larger of the two curves in this space is an attention operating characteristic traced out by manipulating display clutter in the partial report task. The points on this curve indicate that clutter preceding the target pattern affects performance only if it is directionally specific: left clutter facilitates performance when the left target is cued, at the expense of performance when the right target is cued, and conversely, while no clutter and double clutter yield equivalent performances under both cueing conditions. This pattern of data would suggest that clutter distracts the subject, pulling attention to one side of the display. Had the four clutter conditions been arrayed along the operating characteristic in the opposite direction, the pattern would suggest a masking effect of clutter.

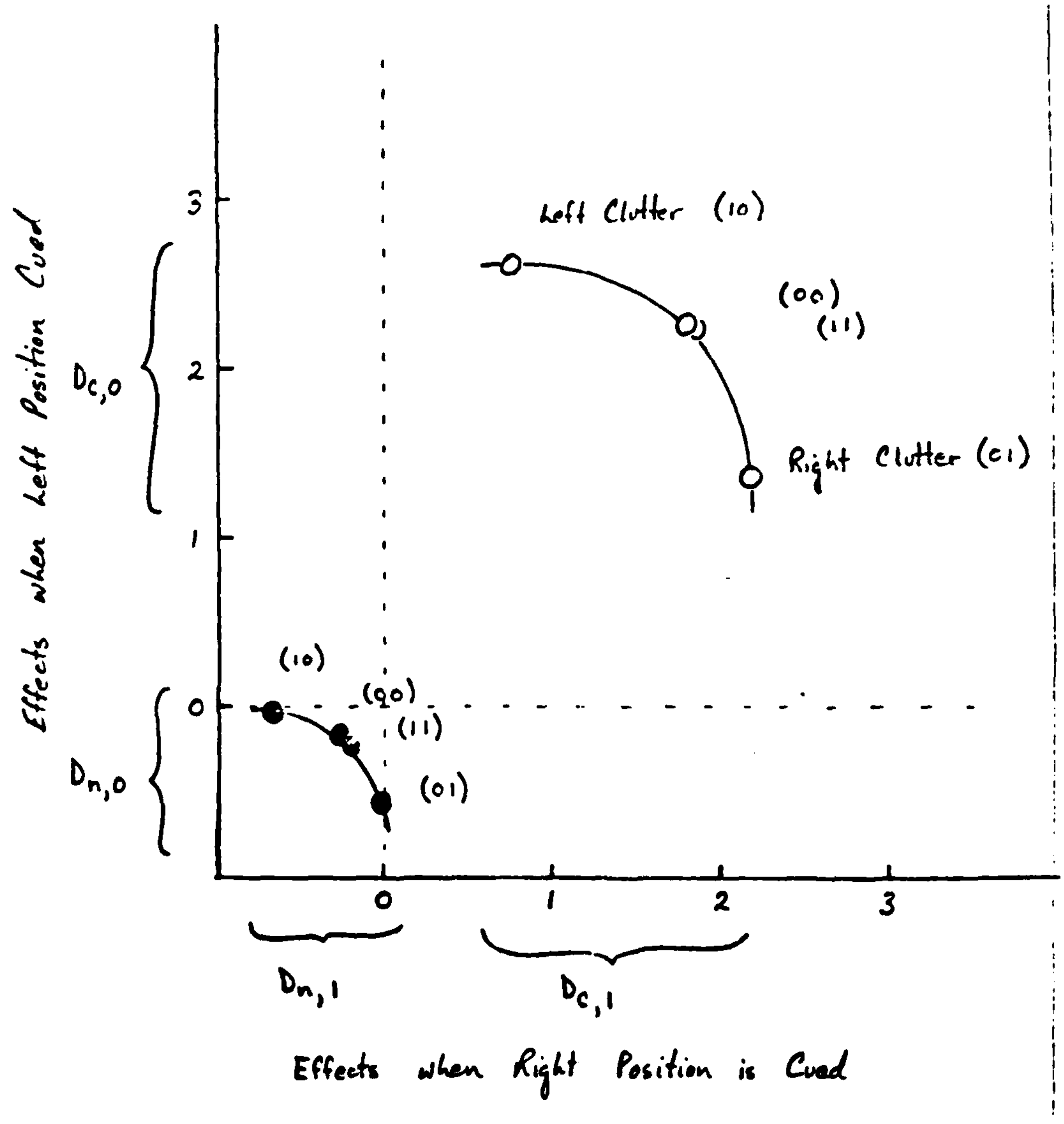

Figure 7. One possible pattern of partial report data. The larger AOC represents cued effects; the smaller AOC represents effects of the non-cued target.

In general, different patterns in the AOC space point to different interpretations of the effect of clutter on cued target performance. A clustering of all four points would indicate no effects of clutter on increment detection at all; such a null result would tell us that the mechanism affected by clutter in temporal judgments (Collyer's findings) is not shared by the process responsible for energy judgments. An upward-sloping AOC might indicate that one direction of distraction facilitates detection of both target increments, while the opposite direction interferes with both, perhaps reflecting lateral asymmetries of information processing. Another possible pattern is one in which points seem to lie on different AOC curves depending on the amount, rather than the direction, of clutter; here, a masking and/or a response error interpretation might be appropriate, depending on the particular pattern.

The smaller curve in Figure 7 shows the effects of the non-cued target for each clutter condition. If subjects were completely successful at ignoring the non-cued target, then the four points on this "incidental AOC" would cluster at the origin of the graph. A systematic pattern in these points, however, would indicate intrusive effects of the non-cued position in judgments (ostensibly) of the cued position. Shown in Figure 7 is a pattern reflecting a "bending over backwards" strategy (all four points represent pairs of D_n less than zero), and an interaction of clutter with this strategy. For example, under the left clutter condition (jk=10), the subject is hypothetically distracted toward the left; as a result, he processes the left target more efficiently than the right; if cued to report the left target, he does so well, with little influence of the right target; however, if cued to report the right target, his response is biased towards saying "no" if there were a left increment, or "yes" if there were no left increment. Such potentiation

of response strategies by patterns of clutter, can thus be examined in the partial report task by analyzing the "incidental AOC".

Modeling of Luminance Increment Detection Clutter

To model sensory responses in the context of clutter during luminance detection, horizontal eye movements will be recorded using a limbus tracking system. During this portion of the work, the display stimuli will be presented entirely in the horizontal plane. The model, in its present form, can then be directly applied since it considers a single spatial dimension, time, and luminance.

Because of the large number of subject trials proposed, it will not be possible to acquire an eye movement measurement at each instance. Nevertheless, it will be possible to obtain several representative recordings from each subject and condition. Inconsistencies in recordings will necessitate more extensive measurements.

Given a set of eye movements, the eye position vs. time function along with the corresponding display pattern will be used to calculate a functional description of the retinal stimulus. The model can then predict the transformation that occurs in the information on the retina as it is dynamically modified by the interaction of temporal and spatial properties.

As discussed in detail in Appendix I, it was previously found that a simple decision rule applied uniformly to the results of the transformation of retinal activation could predict subject responses to apparent blur lengths in a saccadic suppression exponent. Therefore, in the context of the luminance detection clutter experiments, the model can provide output in the form of subject responses. In instances where the model can predict our experimental results then we would have a good

understanding of the mechanisms which arise during clutter conditions. In cases where the model does not predict experimental findings, it will be possible to conclude that those properties included in the model may not be important concerns. The hypothesis: How important are sensory spatial and temporal properties to the detection of luminance changes in clutter conditions? can be tested.

The model does not contain representation of any higher order functions distinguishing between full & partial report conditions. However, there may be distinctly different eye movements under different cueing conditions, or accuracy differences between the two kinds of report, which will point to appropriate model interpretations.

These studies of energy processing in relation to display clutter can provide useful information both for theory development and for design applications. However, pilots must process symbolic as well as energy information. The nature of clutter effects on this higher level of information processing, is the focus of the next part of the project.

C. Processing of Symbols: Alphanumeric Character Recognition

Pilots must read alphanumeric information as well as respond to luminance changes in indicator lights. A comprehensive account of clutter effects must therefore address this level of visual processing, which is arguably more critical to overall flight performance than lower levels. A large literature exists on the processing of alphanumeric symbols in briefly-presented displays; however, effects of display clutter have been largely neglected.

As far as possible, the design of our investigation of symbol recognition will parallel the studies of luminance-increment detection. Both

partial and whole report tasks will be employed in order to assess recognition under instructions both to ignore non-cued information, and to include all processsed information, in the response. For both types of task, a "critical" symbol or class of symbols (e.g. the letter "X; or any even digit; or the word "GO") will be designated. Target display positions may then contain the critical symbol, or a noise symbol (i.e., some non-critical letter, digit, or word). The critical symbol plays a role analogous to that of a luminance increment in the studies of energy processing. Thus, in whole report recognition, the subject would make two yes/no responses, indicating his judgment of the presence or absence of the critical symbol in each of the two target positions. In partial report, one yes/no response would be made, indicating the subject's judgment for the cued position alone.

The parallel design of the luminance-increment phase and the symbol recognition phase of the project, has the advantage that effects of clutter on each type of information processsing can be compared directly, using AOC analysis. It would be possible, for example, to find no attentional tradeoff attributable to clutter in the luminance task, and a strong tradeoff in the symbol task; or, to find that masking at the luminance level accounts for recognition errors; or to find a bending-over-backwards strategy only in recognition. Note that effects of non-cued letters on cued recognition performance represent the very important problem of interference between an attended "message" and an ostensibly non-attended message. The early literature on attention was concerned with this general problem in listening, and later in tachistoscopic visual processing (Broadbent, 1958; Shiffrin & Schneider, 1977; Schneider & Shiffin, 1977). In vision, however, there is again a gap in our knowledge of how clutter interacts with such effects.

Differences between the AOC representations of performance at the two levels may point toward different display design strategies for presenting luminance and symbolic information. For example, suppose that masking were shown to be a source of errors at one level of processing, and distraction at the other. Moving sources of displayed information further apart in a HUD could reduce masking effects, but aggravate distraction effects. Thus the consequences of a design decision will be more accurately foreseen if data is available on the interaction between source of error and type of displayed information. This project is designed to furnish such data.

Modeling of Alpha-numeric Character Recognition

Because character recognition is a two dimensional spatial problem, the model will be expanded into an extra dimension to accept both horizontal and vertical edge movements as an input function. This will increase computer time to calculate response functions. Thus the present mathematical form will be revised to increase its calculational efficiency. Furthermore, because we will be dealing with more dimensions than three, only projection of the resulting g(x,y,t) can be examined statically.

To increase our interpretation ability, however, it will be possible to use a CRT graphics display terminal to generate the extra dimension as an actual time sequence. We will observe the predicted retinal response x,y projection of g(x,y,t) as it moves in time.

Similar analysis as in Section B will then be carried out.

Bibliography

Arend, L., "Temporal Determinants of the Spatial Contrast Threshold MTF," Vis. Res., 16, 1035-1042, 1976.

Breitmeyer, B.G. and Ganz, L. Implications of sustained and transient channels for theories of visul pattern masking, saccadic suppression, and information processing. Psychological Review, 1976, 83, 1-37.

Bridgeman, B., "Reply to Brooks and Fuchs: Exogenous and Endogenous Contributions to Saccadic Suppression: Vis Res, 17, 323-324, 1977.

Broadbent, D.E. Perception and Communication. Oxford: Pergamon, 1958.

Brooks, B., Fuchs, A., "Influence of Stimulus Parameters on Visual Sensitivity During Saccadic Eye Movements," Vis. Res., 15, 1389-1398.

Collyer, C.E. The induced asynchrony effect: Its role in visual judgments of temporal order and its relation to other dynamic perceptual phenomena. Perception & Psychophysics, 1976, 19, 47-54.

Cornsweet, N. "Visual Perception," Academic Press, 1970.

Furchner, C., Thomas, J., Campbell, F., "Detection and Discrimination of Simple and Complex Patterns at Low Spatial Frequencies," Vis. Res., 17, 827-836.

Glezer, V.D., Gauzelman, V., Tsherbach, T., Dudkin, K., "Comments on Organization and Spatial-Frequency Characteristics of Receptive Fields in the Visual Cortex," Vis. Res., 18, 887-889, 1978.

Grunau, M., "Interaction between Sustained and Transient Channels: Form Inhibits Motion in the Human Visual System," Vis. Res., 18, 197-201, 1978.

Hines, M., "Line Spread Function Variation Near the Fovea," Vis. Res., 16, 567-572, 1976.

Jonides, J. Voluntary vs. reflexive control of the mind's eye movement. Presented at Psychonomic Society Convention, St. Louis, Mo., November 1976.

Kahneman, D. Method, findings, and theory in studies of visual masking. Psychological Bulletin, 1968, 70, 404-425.

Kinchla, R.A. The role of structura redundancy in the perception of visual targets. Perception & Psychophysics, 1977, 22, 19-30.

Kinchla, R.A. The measurement of attention. Presented at the Eighth Attention & Performance Symposium, Princeton, N.J., August 1978.

Klein, R. Cognitive and reflexive control of attention in vision. Presented at the Eighth Attention & Performance Symposium, Princeton, N.J., August 1978.

Legge, G., "Sapce Domain Properties of a Spatial Frequency Channel in Human Vision: Vis. Res., 18, 959-969, 1978.

Mackay, D., "Elevation of Visual Threshold by Displacement of Retinal Image," Nature, 225, 90-92, 1970.

Matin, E., "Saccadic Suppression: A Review and an Analysis," Psychol., Bull., 81, 899-917, 1974.

Matin, E., Clymer, A., Matin, L., "MetaContrast and Saccadic Suppression, Science, 178, 179-182.

Matin, L., "A possible hybrid mechanism for modification of visual direction associated with eye movements - The Paralyzed Eye Experiment Reconsidered," Perception, 5, 233-239, 1976.

Matin, L., Matin, E., "Visual Perception of Direction and Voluntary Saccadic Eye Movements." Biblio. Ophthal, 82, 358-368, 1976.

Matin, L., "Eye Movements and Perceived Visual Direction, "Handbook of Sensory Physiology, 8, Visual Psychophysics, 332-380, 1972.

Mitrani, L., Radil-Weiss, T., Yakimoff, N., Mateeff, S., Bozkov, V., "Determination of Vision Due to Contour Shift Over the Retina During Eye Movements," Vis. Res., 15 877-878, 1975.

Navon, D. and Gopher, D. On the economy of the human processing system. Psychological Review, 1979, 86, 214-255.

Ohley, W.J., Kao, C., Jaron, D., Validity of an Arterial System Model: A Quantitative Evaluation, IEEE Trans. On Biomedical Engineering BME, 1980.

Ohley, W.J., "A Computer Model of Saccadic Suppression," USAF Mini Grant Program Final Report, 1979.

Sakitt, B., "Information Received from Unseen Lights," Vis. Res., 16, 782-784, 1976.

Schneider, W. nd Shiffrin, R.M. Controlled and automatic human information processing: I. Detection, search, and attention. Psychological Review, 1977, 84, 1-66.

Shebilske, W., "Extra Retinal Information in Corrective Saccades and Inflow vs. Outflow Theories of Visual Direction Constancy," Vis. Res., 16, 621-628, 1976.

Shiffrin, R.M. and Schneider, W. Controlled and automatic human information processing: II. Perceptual learning, automatic attending, and a general theory. Psychological Review, 1977, 84, 127-190.

Sperling, G. and Melchner, M. The attention operating characteristic: Examples from visual search. Science, 1978, 202, 315-318.

Spitzberg, R., Richards, W., "Broad Band Spatial Filters in the Human Visual System," Vis. Res., 15, 837-841, 1975.

Stark, L., Kong, R., Schwartz, S., Hendry, D., Bridgemen, B., "Saccadic Suppression of Image Displacement," Vis. Res., 16, 1185-1187, 1976.

Volkman, F., Riggs, L., White, K., Moore, R., "Contrast Sensitivity During Saccadic Eye Movements, : Vis Res., 18, 1193-1199, 1978.

Wilson, H., Phillips, G., Bentschlen, I., Hilz, R., "Spatial Probability Summation and Disinhibition in Psycholophysically Measured Line Spread Functions," Vis. Res., 19, 593-598, 1979.

Wilson, H., "Quantitative Charracterization of Two Types of Line Spread Function Near the Fovea: Vis. Res., 18, 971-981, 1978.

Yarbus, A., "Eye Movements and Vision," Plenum Press, 1967.

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